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(54) **SURGICAL INSTRUMENT AND CONTROL METHOD THEREOF**

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USPC 700/245, 253, 257, 258, 259, 260, 261, 700/262, 264; 318/568.11, 568.12, 568.14, 318/568.16, 568.21; 901/1, 2, 8, 9, 30, 31, 901/34, 46; 606/1, 205
See application file for complete search history.

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(57) **ABSTRACT**

A surgical instrument includes an end effector, a manipulation unit, a grip detecting unit, a driving unit, and a control unit. When the control unit determines that the end effector is applying the acting force to the target based on the information acquired by the grip detecting unit, the control unit sets an acting force increasing zone of a predetermined range in a first movable range in the first direction of the manipulation unit, sets a neutral zone in a remaining area of the first movable range, controls the driving unit so that the acting force increases with a constant gradient with respect to an amount of manipulation of the manipulation unit in the acting force increasing zone, and controls the driving unit so that the acting force is kept constant regardless of the amount of manipulation of the manipulation unit in the neutral zone.

7 Claims, 13 Drawing Sheets

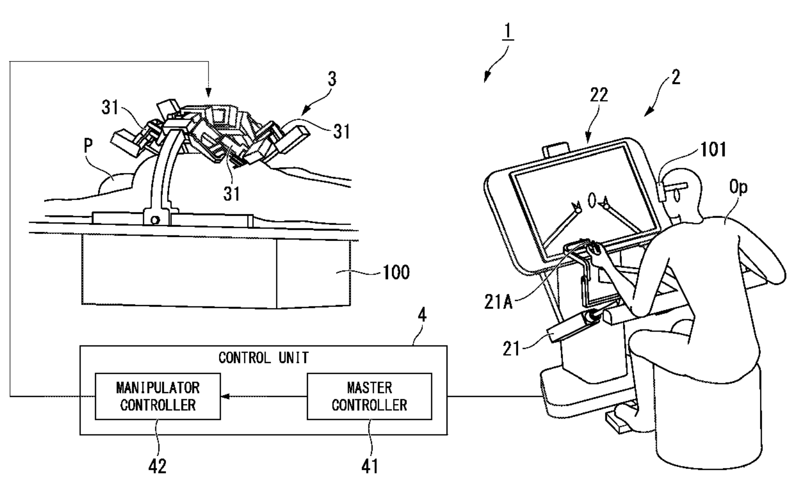

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FIG. 1

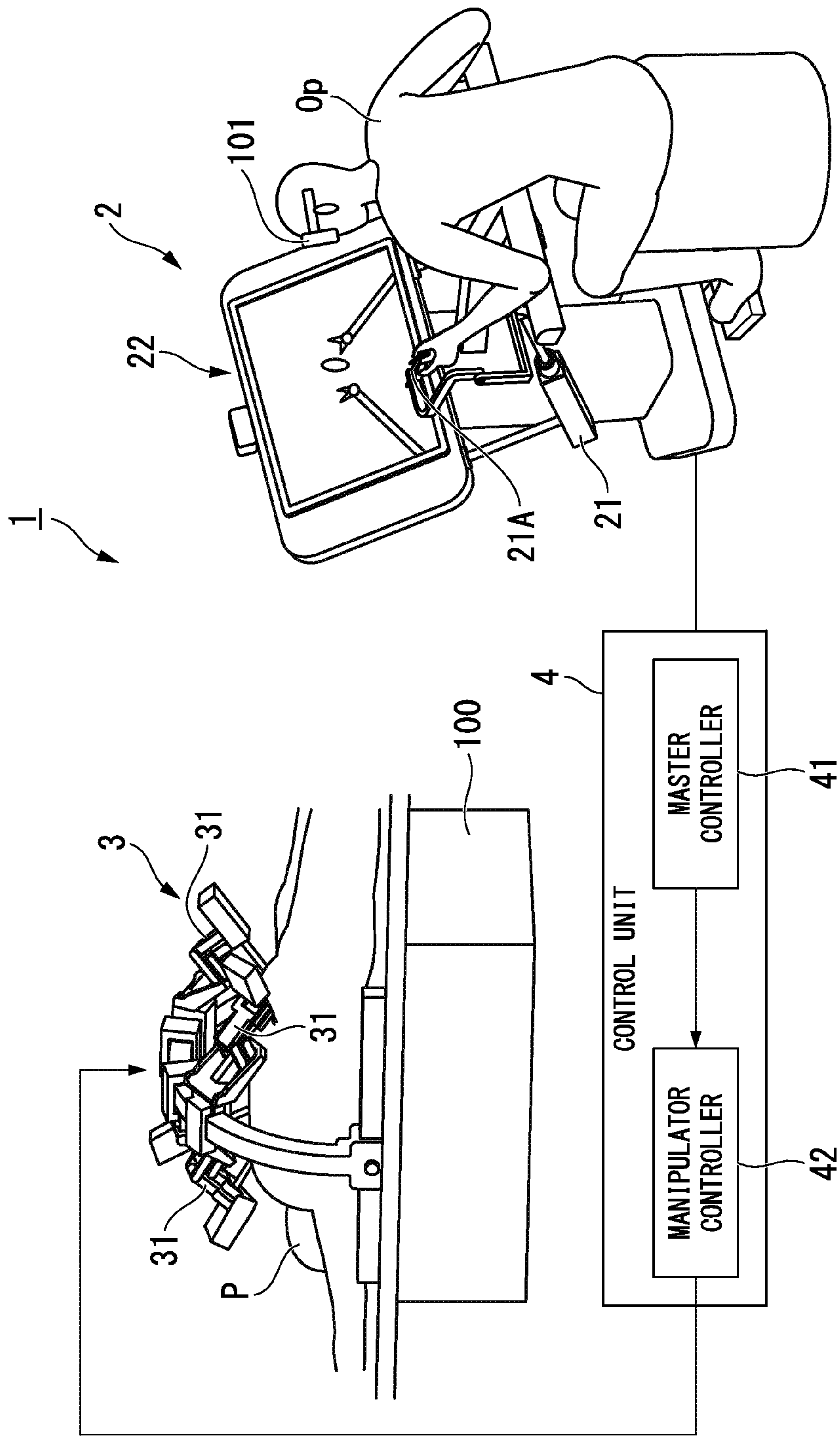
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FIG. 2

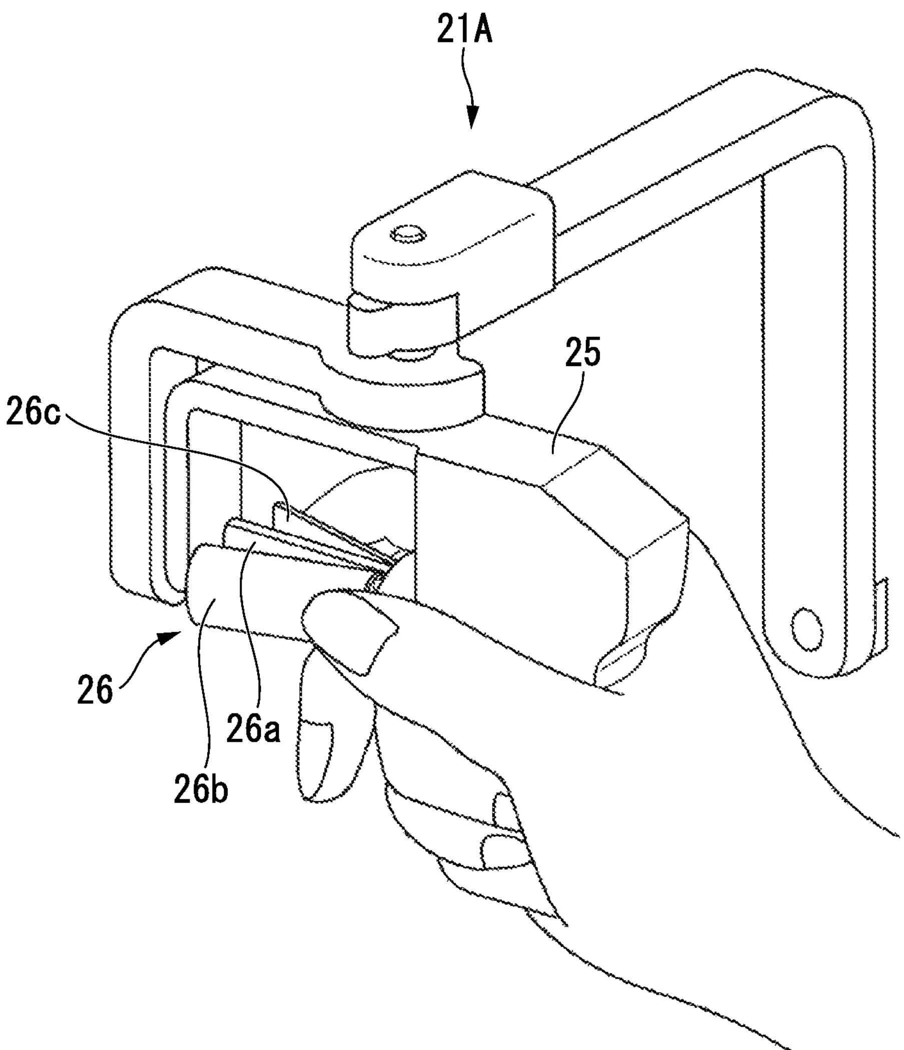


FIG. 3

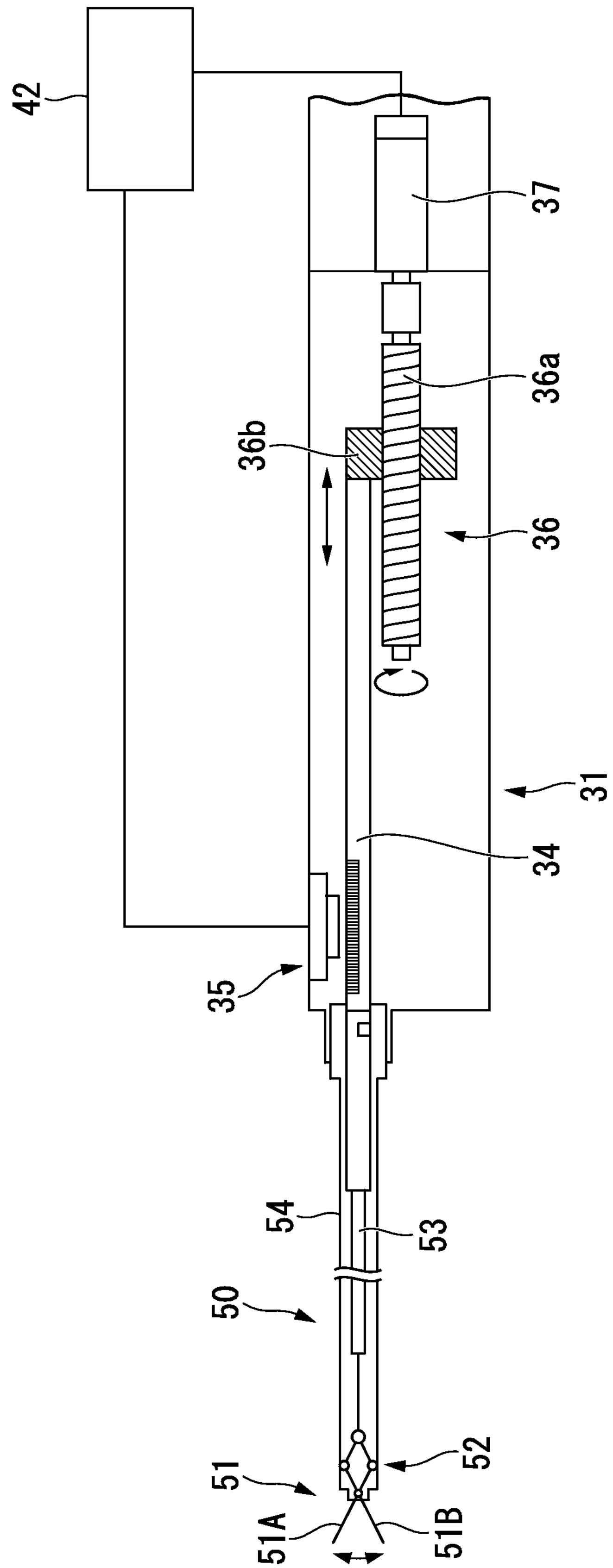


FIG. 4

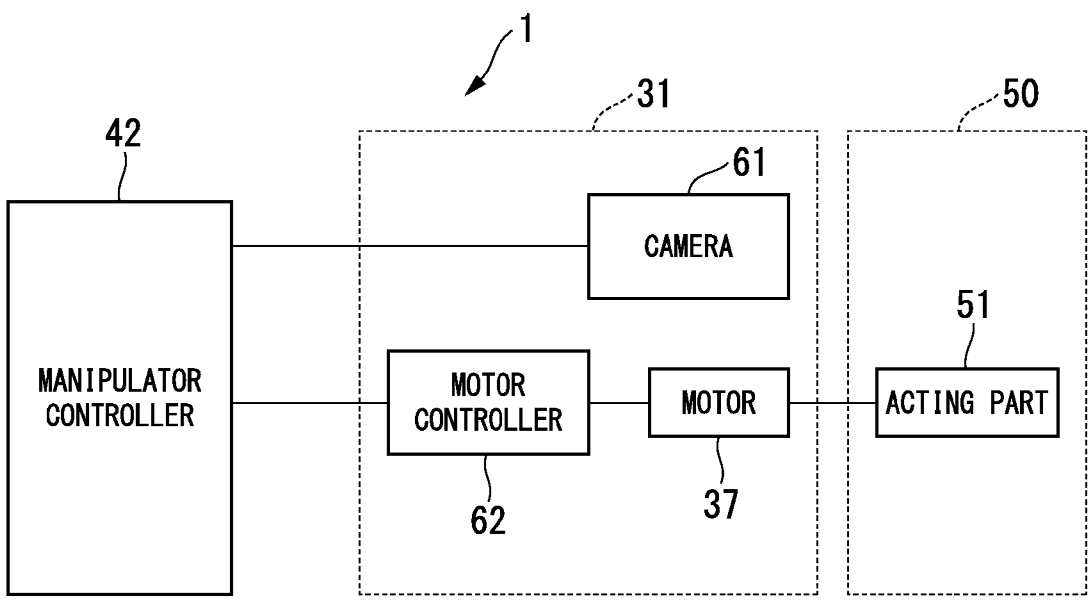

1
31
50
42
61
CAMERA
51
MANIPULATOR CONTROLLER
MOTOR CONTROLLER
MOTOR
ACTING PART
62
37

FIG. 5

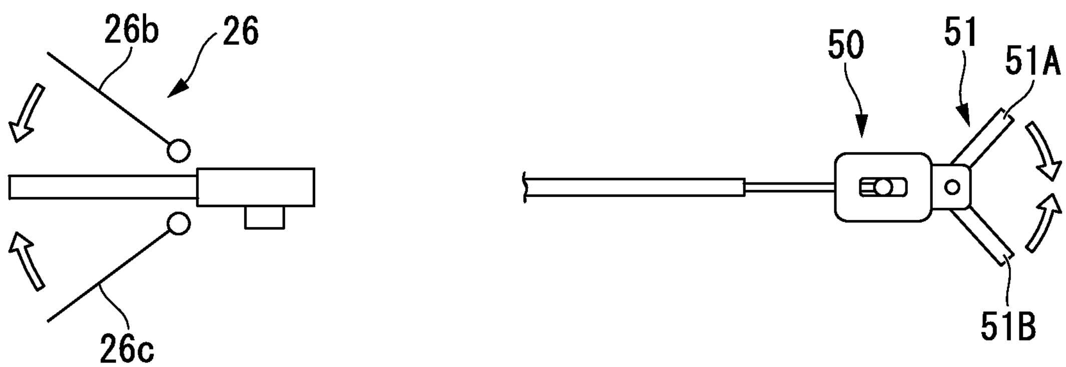


FIG. 6

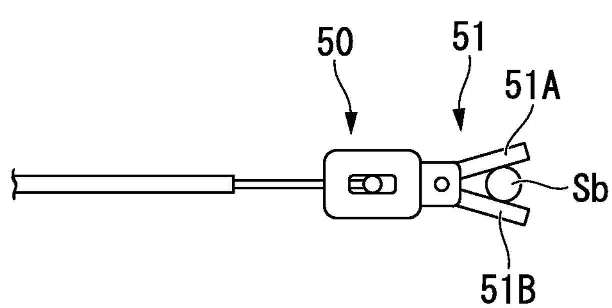


FIG. 7

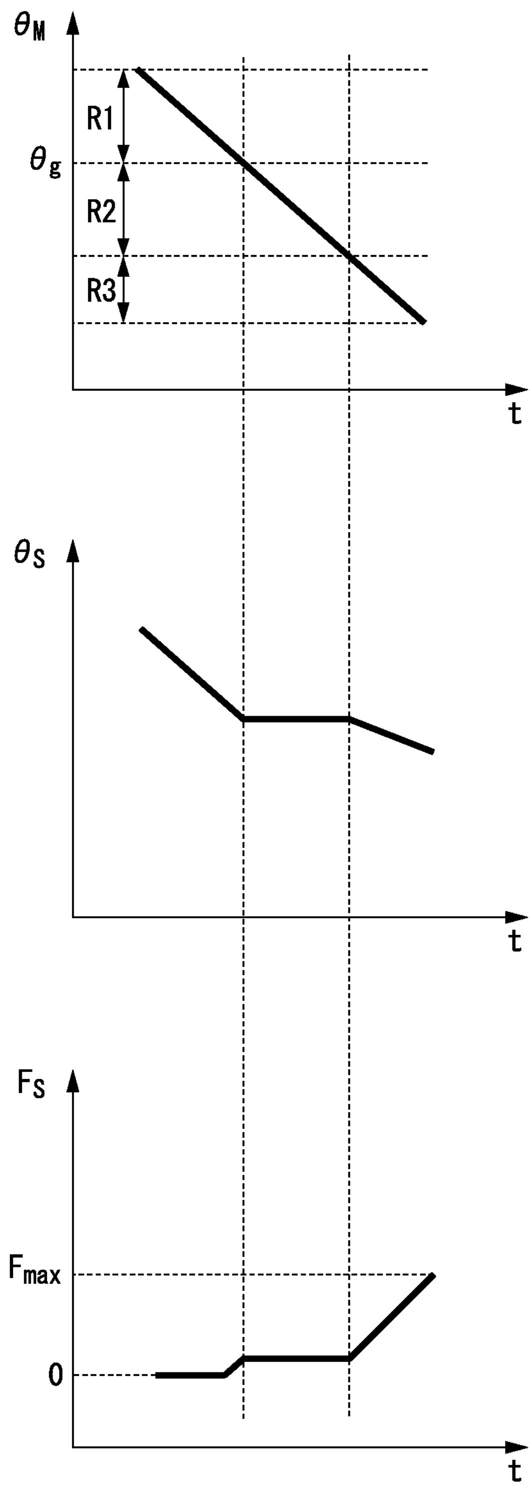
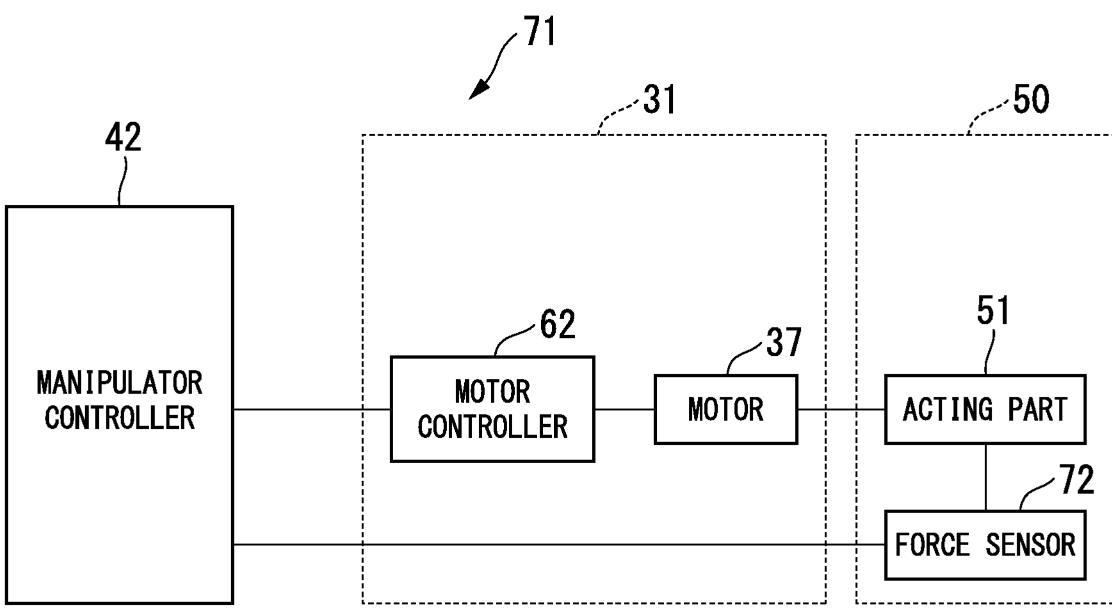


FIG. 8



71
31
50
42
MANIPULATOR CONTROLLER
62
MOTOR CONTROLLER
37
MOTOR
51
ACTING PART
72
FORCE SENSOR

FIG. 9

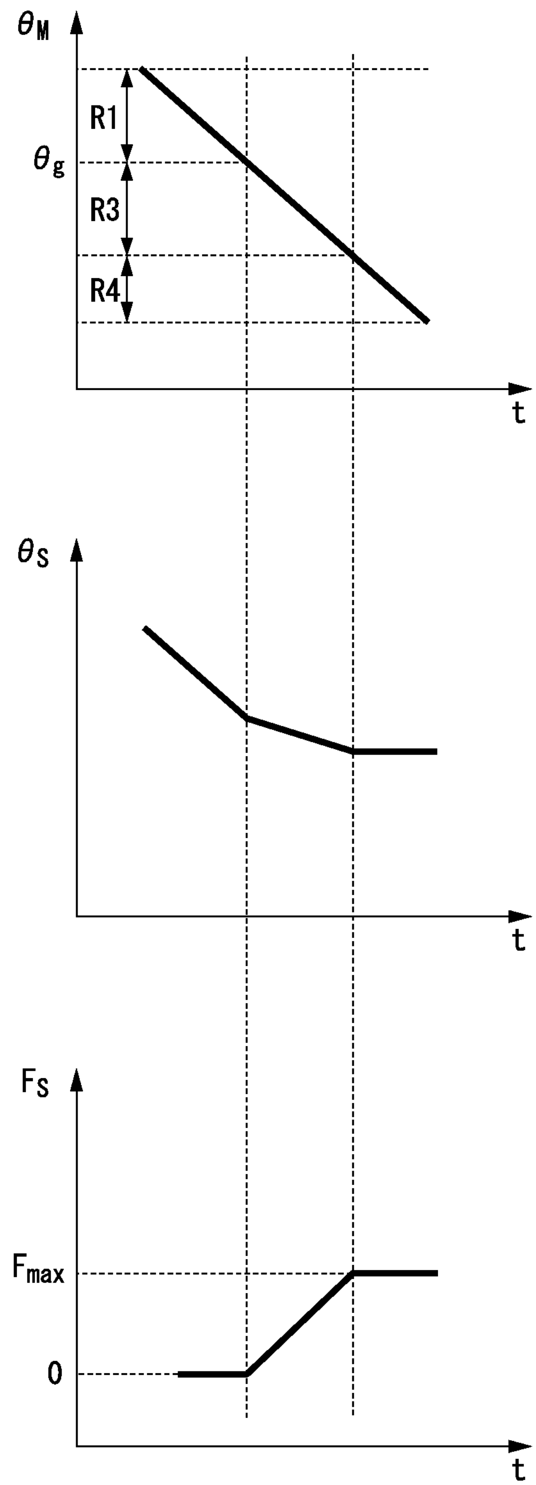
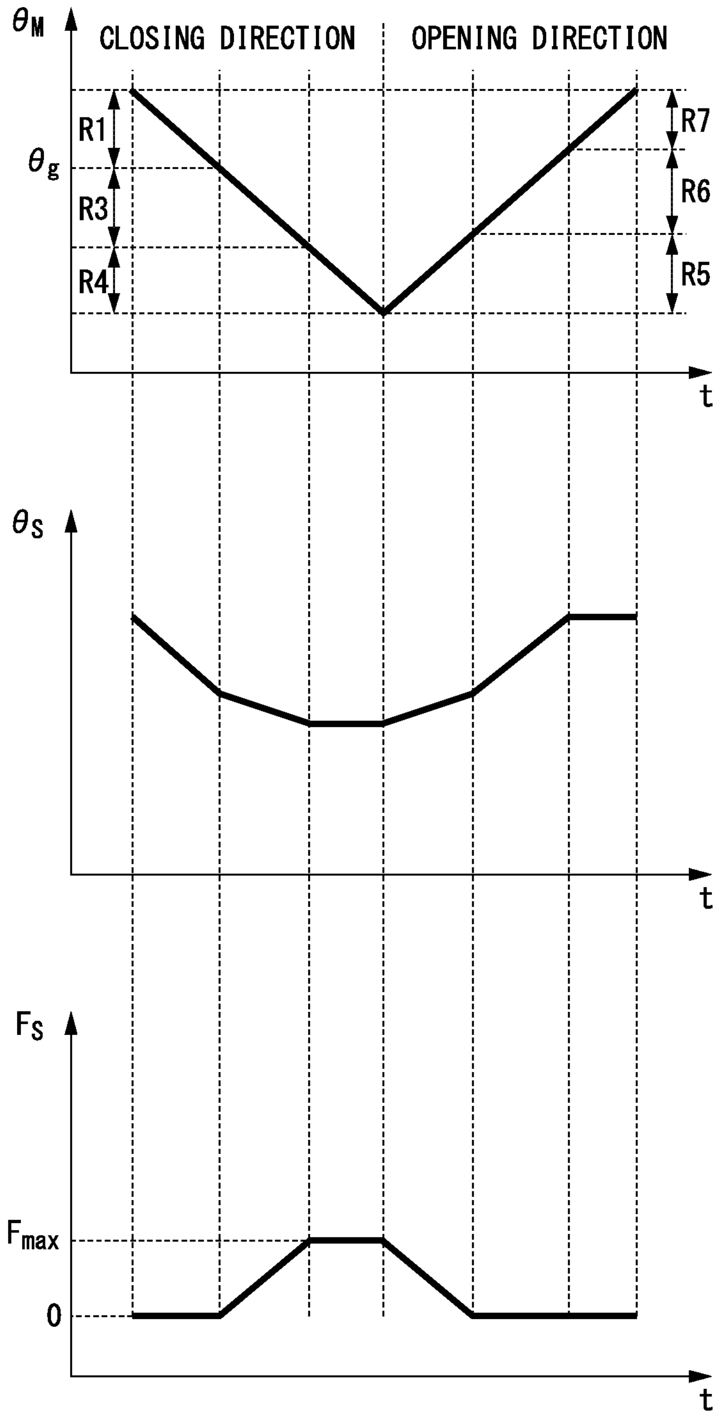
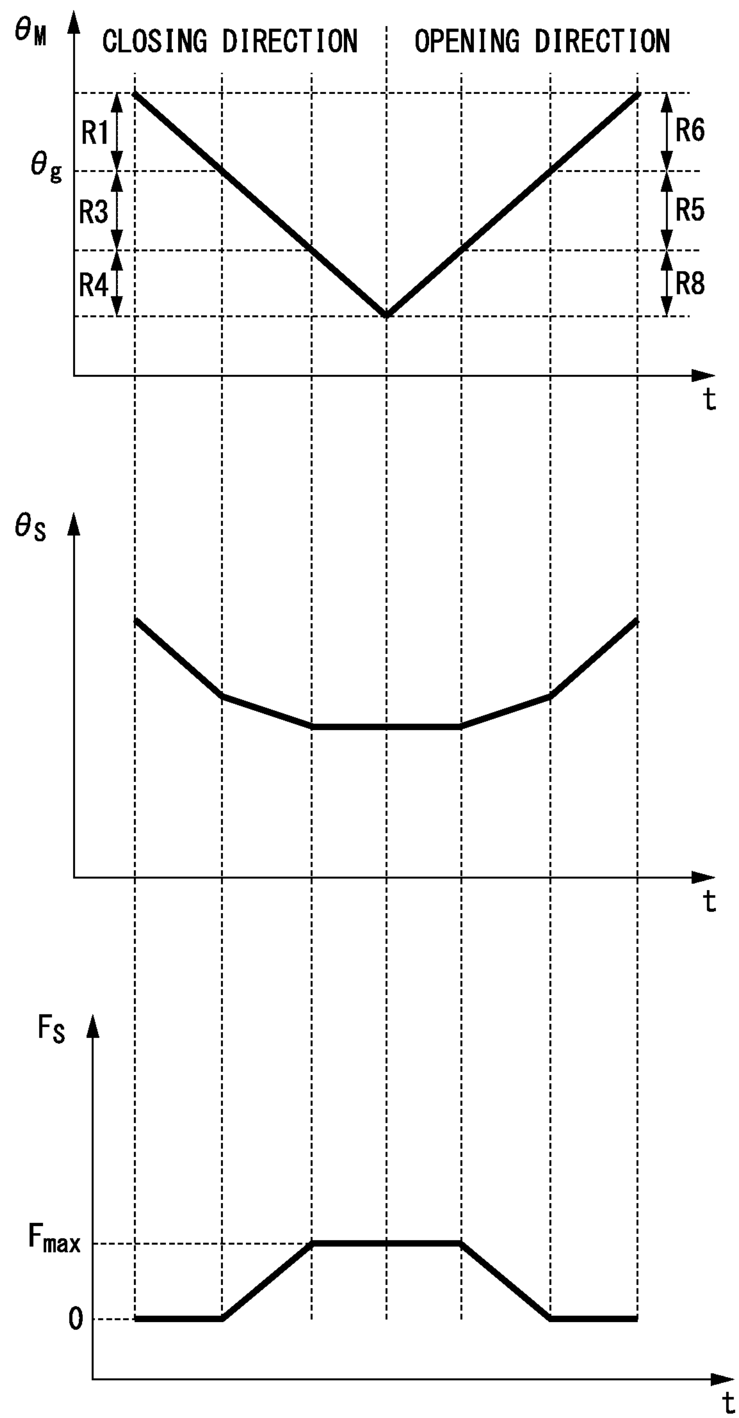


FIG. 10



θM
CLOSING DIRECTION
OPENING DIRECTION
R1
θg
R3
R4
R7
R6
R5
t
θS
t
FS
Fmax
0
t

FIG. 11



θ_M
CLOSING DIRECTION
OPENING DIRECTION
R1
θ_g
R3
R4
R6
R5
R8
t
θ_S
t
F_S
F_{max}
0
t

FIG. 12

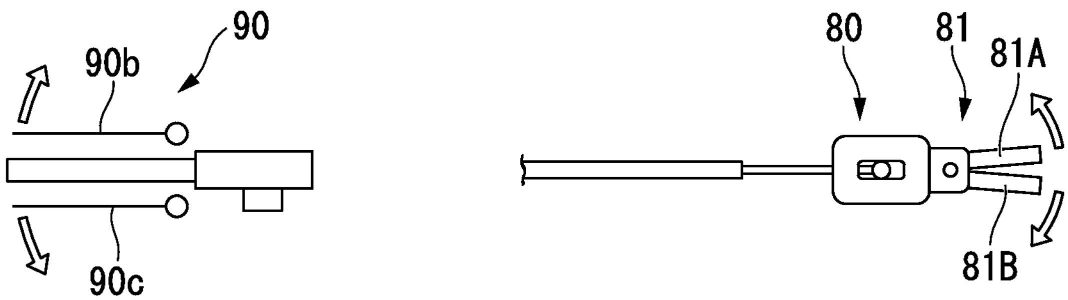


FIG. 13

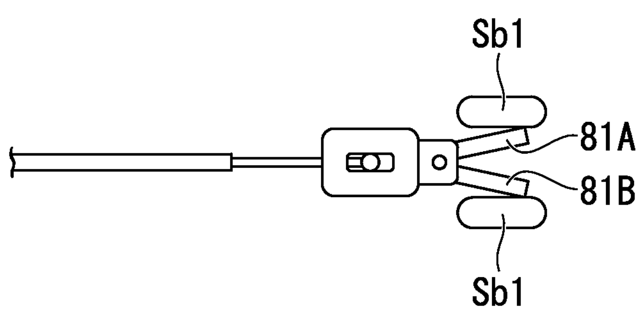


FIG. 14

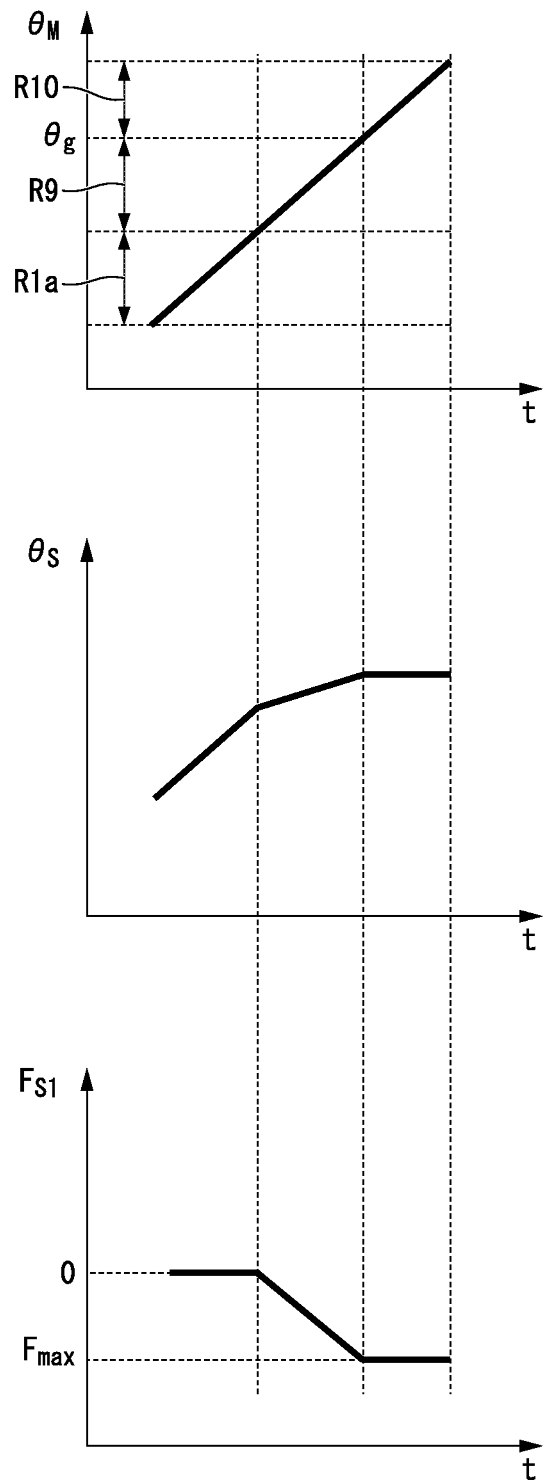
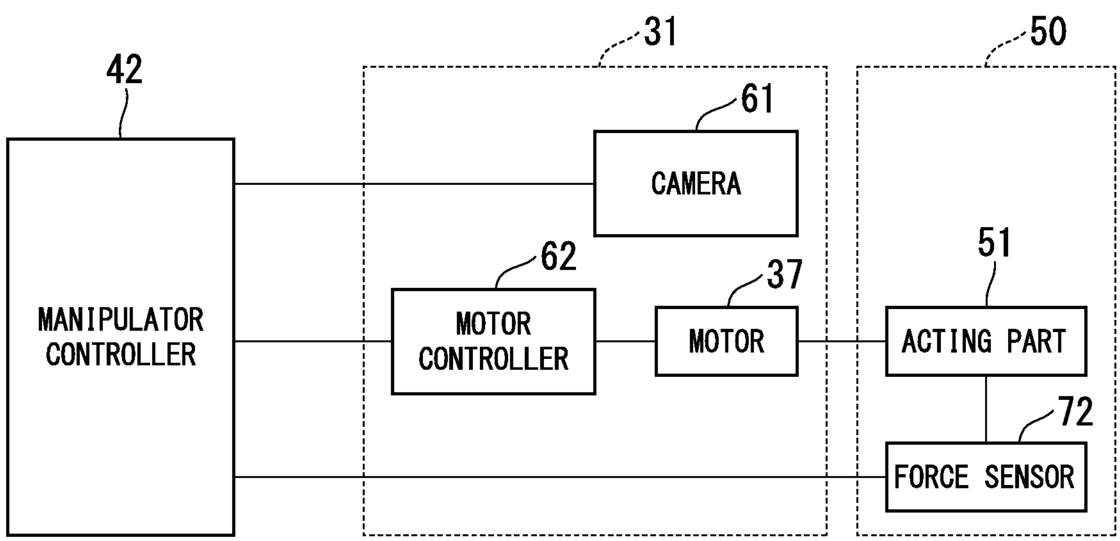


FIG. 15



31
50
42
61
CAMERA
62
37
51
MANIPULATOR CONTROLLER
MOTOR CONTROLLER
MOTOR
ACTING PART
72
FORCE SENSOR

SURGICAL INSTRUMENT AND CONTROL METHOD THEREOF

This application is a continuation application based on PCT/JP2012/070576, filed on Aug. 6, 2012, claiming priority based on Japanese Patent Application No. 2012-031959, filed Feb. 16, 2012 and U.S. Patent Application No. 61/515,203, filed Aug. 4, 2011. The contents of the Japanese Patent Application, U.S. Patent Application and the PCT Application are incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a surgical instrument having an end effector that is opened and closed and a control method thereof.

2. Description of Related Art

In the medical field, various surgical instruments are known. A surgical instrument having an end effector that is opened and closed is known as one of such surgical instruments. Since the end effector is used to grip or exclusion body tissue, it is important to appropriately control an acting force such as a gripping force or a displacing force that the end effector applies to the body tissue.

Japanese Unexamined Patent Application, First Publication No. 2010-076012 discloses a manipulator system as a surgical instrument in which a gripper as an end effector is driven with a motor. In this manipulator system, a gripping-start angle is recognized on the basis of the output of a gripping-start estimating observer. A control is performed so that the gripping force is increased after gripping is started and a desired gripping force is achieved when the opening angle of the gripper reaches the most closed angle.

SUMMARY OF THE INVENTION

According to a first aspect of the invention, a surgical instrument including: an end effector that is opened and closed; a manipulation unit configured to manipulate the end effector in a first direction so that the end effector applies an acting force to a target; a grip detecting unit configured to acquire an information used to determine whether the end effector applies the acting force to the target; a driving unit configured to drive the end effector to be opened and closed; and a control unit configured to control the driving unit based on the information input to the manipulation unit, when the control unit determines that the end effector applies the acting force to the target based on the information acquired by the grip detecting unit, the control unit sets an acting force increasing zone of a predetermined range in a first movable range in the first direction of the manipulation unit, sets a neutral zone in a remaining area of the first movable range, controls the driving unit so that the acting force increases with a constant gradient with respect to an amount of manipulation of the manipulation unit in the acting force increasing zone, and controls the driving unit so that the acting force is kept constant regardless of the amount of manipulation of the manipulation unit in the neutral zone.

According to a second aspect of the invention, in the first aspect, the acting force increasing zone may be set in an initial area toward the first direction in the first movable range.

According to a third aspect of the invention, in the first aspect or the second aspect, the grip detecting unit may include a camera imaging the end effector.

According to a fourth aspect of the invention, in any one of the first aspect to the third aspect, the grip detecting unit may include a force sensor detecting the acting force.

According to a fifth aspect of the invention, in any one of the first aspect to the fourth aspect, the first movable range of the manipulation unit may be set to be greater than a movable range of the end effector.

According to a sixth aspect of the invention, in the second aspect, the acting force may decrease when the manipulation unit is manipulated in a second direction, and when the manipulation unit may be manipulated in the second direction, the control unit may set an acting force decreasing zone of a predetermined range to an initial area toward the second direction in a second movable range of the second direction of the manipulation unit, and may control the driving unit so that the acting force decreases with a constant gradient with respect to the amount of manipulation of the manipulation unit in the acting force decreasing zone.

According to a seventh aspect of the invention, a control method of a surgical instrument having an end effector that is opened and closed and a manipulation unit configured to manipulate the end effector in a first direction so that the end effector applies an acting force to a target, the control method includes: repeatedly determining whether the end effector applies the acting force to the target; when determining that the end effector applies the acting force to the target, setting an acting force increasing zone of a predetermined range in a first movable range in the first direction of the manipulation unit, setting a neutral zone in a remaining area of the first movable range; causing the acting force to increase with a constant gradient with respect to an amount of manipulation of the manipulation unit in the acting force increasing zone; and causing the acting force to be kept constant regardless of the amount of manipulation of the manipulation unit in the neutral zone.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram schematically illustrating the configuration of a medical master-slave manipulator according to a first embodiment of the invention.

FIG. **2** is an enlarged view illustrating a grip section of the medical master-slave manipulator.

FIG. **3** is a diagram schematically illustrating the structure of a distal end of a slave arm in the medical master-slave manipulator.

FIG. **4** is a block diagram illustrating the functional relation of a manipulator controller, a distal end of a slave arm, and a treatment tool in the medical master-slave manipulator.

FIG. **5** is a diagram illustrating the correspondence of the manipulation on an end effector manipulating part and the movement of an acting part of a treatment tool.

FIG. **6** is a diagram illustrating a state where the acting portion grips a target.

FIG. **7** is an example of a graph illustrating the relationship of an opening angle of an opening and closing member, an opening angle of an end effector, and a gripping force in the medical master-slave manipulator.

FIG. **8** is a block diagram illustrating the functional relation of a manipulator controller, a distal end of a slave arm, and a treatment tool in a medical master-slave manipulator according to a second embodiment of the invention.

FIG. **9** is an example of a graph illustrating the relationship of an opening angle of an opening and closing member, an opening angle of an end effector, and a gripping force in the medical master-slave manipulator.

FIG. **10** is an example of a graph illustrating the relationship of an opening angle of an opening and closing member, an opening angle of an end effector, and a gripping force in a medical master-slave manipulator according to a third embodiment of the invention.

FIG. **11** is an example of a graph illustrating the relationship of an opening angle of an opening and closing member, an opening angle of an end effector, and a gripping force according to a modified example of the medical master-slave manipulator.

FIG. **12** is a diagram illustrating the correspondence of the manipulation on an end effector manipulating part and the movement of an acting part of a treatment tool in a medical master-slave manipulator according to a fourth embodiment of the invention.

FIG. **13** is a diagram illustrating a state where the acting part presses a target.

FIG. **14** is an example of a graph illustrating the relationship of an opening angle of an opening and closing member, an opening angle of an end effector, and a gripping force in the medical master-slave manipulator.

FIG. **15** is a block diagram illustrating the functional relation of a manipulator controller, a distal end of a slave arm, and a treatment tool in a medical master-slave manipulator according to a modified example of the invention.

DETAILED DESCRIPTION OF THE INVENTION

Hereinafter, a first embodiment of the invention will be described. FIG. **1** is a diagram illustrating a medical master-slave manipulator (hereinafter, simply referred to as a "master-slave manipulator") **1** which is a surgical instrument according to this embodiment. The master-slave manipulator **1** includes a master input unit **2** having a master arm **21** and outputting a manipulation command and a slave manipulator **3** having a slave arm **31**. The master-slave manipulator **1** remotely controls the slave arm **31** to follow the manipulation of the master arm **21** by an operator (user) Op. The manipulation command from the master arm **21** is transmitted to a master controller **41** of a control unit **4** and is input to a manipulator controller **42**. Thereafter, a motion signal is sent from the manipulator controller **42** to the slave manipulator **3** and the slave arm **31** moves.

As shown in FIG. **1**, the slave manipulator **3** is installed in an operating table **100** on which a patient P is placed and includes plural slave arms **31**. Each slave arm has plural multi-degree-of-freedom joints and can move multi-axially. The multi-degree-of-freedom joints are individually driven by a power unit not shown. For example, a motor (servo motor) having a servo mechanism including an incremental encoder or a decelerator can be used as the power unit.

One of the plural slave arms **31** is provided with observation device not shown such as an endoscope that captures an image of the field of operation related to a manipulation target site and the other slave arm is provided with a treatment tool performing a variety of treatment to be described later. Known observation device can be appropriately selected and used as the observation device. Each slave arm includes a drive source that drives the treatment tool and the like. For example, a servo motor can be used as the drive source. In the following description, the slave arm provided with a treatment tool out of the slave arms may be also referred to as a "slave arm for treatment".

The master input unit **2** includes plural master arms **21** to be manipulated by an operator Op and a display unit **22** on which an image acquired by the observation device. Each master arm **21** has a known configuration which can multi-axially move and a grip section (manipulation unit) **21**A which is gripped by the operator at a tip end close to the operator Op. The display unit **22** is constructed by a known display or the like and displays an image of a field of operation acquired by the observation device. In this embodiment, two images having a difference corresponding to parallax are projected onto the display unit **22** and the operator Op can stereoscopically view an image through the use of known 3D glasses **101** having a polarizing mechanism, a shutter mechanism, or the like.

FIG. **2** is an enlarged view of the grip section **21**A. The grip section **21**A includes a grip body **25** to be gripped by the operator Op and an end effector manipulating part (manipulation unit) **26** to be opened and closed by the operator.

The operator Op grips the grip body **25** with his or her hand. The joints of the master arm **21** move with the change in the position and the orientation of the grip body **25**, when the position and the orientation of the grip section **21**A is changed with the movement of a wrist, an elbow, and a shoulder. The degrees of movement of the joints are detected by position detectors disposed around the joints and a manipulation signal corresponding to the degrees of movement is input to the master controller **41**. Thereafter, the slave arm **31** corresponding to the master arm is driven in response to the signal sent from the manipulator controller **42**, and the position and the orientation of the end effector of the treatment tool attached to the slave arm correspond to the position and the orientation of the grip body **25**.

The end effector manipulating part **26** includes a base **26*a*** and a pair of opening and closing members **26*b*** and **26*c*** opening and closing with respect to the base **26*a*** at the same angle. The opening angle of the opening and closing members **26*b*** and **26*c*** about the base **26*a*** is detected by detection device such as a encoder not shown and is transmitted to the master controller **41**.

FIG. **3** is a diagram schematically illustrating the structure of a distal end of the treatment slave arm **31**. A treatment tool **50** is attached to the distal end of the treatment slave arm **31**. In this embodiment, the treatment tool **50** is detachably attached to the treatment slave arm **31**, but may not be attached and detached necessarily.

The treatment tool **50** includes an acting part (end effector) **51**, a drive link **52**, and a driving part **53** sequentially from the distal end directed to a body cavity of a patient P to the proximal end connected to the treatment slave arm **31**. The drive link **52** and the driving part **53** are contained in a cylindrical chassis **54**.

The acting part **51** includes, for example, a pair of jaws **51**A and **51**B that can be opened and closed. When the pair of jaws is closed, the acting part interposes and grips a target such as body tissue or a curved needle therebetween and applies a gripping force (acting force) to the target. The driving part **53** is a rod-shaped member and is connected to a drive rod (to be described later) in the slave arm **31** when the treatment tool **50** is connected to the slave arm **31**. The driving part **53** advances or retreats a protopodite of the drive link **52** in the axis direction of the chassis **54** through driving force transmitted from the drive rod. Accordingly, the driving part **53** opens and closes the acting part **51**. The drive link **52** connects the acting part **51** and the driving part **53** and a known link mechanism can be used.

A drive rod **34**, a linear encoder **35**, a linear driving mechanism **36**, and a motor (driving unit) **37** are disposed at the distal end of the slave arm **31**. The linear driving mechanism **36** has a known configuration including a ball screw **36*a*** and a linear driving block **36*b*** and converts the rotational movement of the motor **37** into the advance or retreat movement of the linear driving block **36***b*, which opens and closes the acting part **51**. The proximal end of the drive rod **34** is connected to the linear driving block **36***b*, advances or retreats in the length direction thereof with the advance or retreat movement of the linear driving block **36***b* to cause the driving part **53** of the connected treatment tool **50** to advance or retreat. The amount of movement of the drive rod **34** is detected by the linear encoder **35**.

FIG. **4** is a block diagram illustrating the functional relation of the manipulator controller **42**, the distal end of the slave arm **31**, and the treatment tool **50**. Accordingly, connections to joints other than the manipulator controller **42** and the distal end of the slave arm are not shown.

A camera (grip detecting unit) **61** imaging the state of the acting part **51** of the treatment tool **50** and a motor controller **62** controlling the driving of the motor **37** based on input information input to the grip section **21**A are disposed at the distal end of the slave arm **31**. The camera **61** and the motor controller **62** are connected to the manipulator controller **42**. The camera **61** images the acting part **51** at a predetermined time interval such as several tens of millimeter seconds (msec) and sequentially transmits the acquired images to the manipulator controller **42** as an information used to determine whether the acting part **51** grips a target. The motor controller **62** controls the current value applied to the motor **37** and the current application time in response to a command from the manipulator controller **42** and controls the magnitude of the driving force generated in the motor **37** and the driving time.

The operation of the master-slave manipulator **1** having the above-mentioned configuration will be described below.

An operator Op manipulates a master arm **21** to cause a corresponding treatment slave arm **31** to move and to cause the acting part **51** of the attached treatment tool **50** to approach a gripping target such as body tissue or a curved needle. When the operator grips the opening and closing members **26***b* and **26***c* of the end effector manipulating part **26** in a state where the gripping target is located between a pair of jaws **51**A and **51**B of the acting part **51**, the angle (opening angle) formed by the opening and closing members **26***b* and **26***c* gradually decreases. This change is transmitted to the master controller **41** and the manipulator controller **42** as a detection value of the detection device. The manipulator controller **42** creates a control signal to be transmitted to the motor controller **62** based on the state of the end effector manipulating part **26** and the image transmitted from the camera **61**, and transmits the created control signal to the motor controller **62**. A mode of creating the control signal to be transmitted to the motor controller **62** will be described below in detail.

The manipulator controller **42** sequentially processes the images transmitted from the camera **61** and repeatedly determines whether a target is gripped between a pair of jaws **51**A and **51**B. A control signal to be transmitted to the motor controller **62** is created so that the amount of manipulation on the end effector manipulating part **26** and the amount of opening and closing of the acting part **51** have predetermined correspondence until the pair of jaws **51**A and **51**B comes in contact with the target to grip the target between the pair of jaws **51**A and **51**B. As a result, as shown in FIG. **5**, the pair of jaws **51**A and **51**B is closed in accordance with the amount of closing of the opening and closing members **26***b* and **26***c* of the end effector manipulating part **26**. At this time, the variation in opening angle (hereinafter, also referred to as an "opening-closing member opening angle") of the opening and closing members **26***b* and **26***c* of the end effector manipulating part **26** the variation in opening angle of the pair of jaws **51**A and **51**B may correspond to each other in a one-to-one manner or may correspond to each other with a predetermined coefficient multiplied thereby.

In this embodiment, the opening angle of the pair of jaws **51**A and **51**B is controlled by controlling the driving of the motor **37** in response to the control signal to the motor controller **62**. Alternatively, the opening angle of the pair of jaws may be controlled through an image process on the image acquired by the camera **61** or the opening angle of the pair of jaws may be controlled based on the detection value of the linear encoder **35**.

As shown in FIG. **6**, when the manipulator controller **42** determines that a gripping target Sb comes in contact with the pair of jaws **51**A and **51**B and is gripped between the pair of jaws **51**A and **51**B, the manipulator controller **42** switches the mode of creating a control signal to be transmitted to the motor controller **62**. The manipulator controller **42** compares the present value of the opening-closing member opening angle with the structural minimum value of the opening-closing member opening angle, sets a gripping force increasing zone of a predetermined range in a movable range (first movable range) in the closing direction (first direction) of the opening and closing members **26***b* and **26***c* at the gripping-start time point, and sets a neutral zone in the other range. The above-mentioned minimum value may be negative when the opening and closing members **26***b* and **26***c* can be further manipulated to the closing direction even after the opening and closing members **26***b* and **26***c* are parallel to the base **26***a*.

The "neutral zone" in the first embodiment of the invention means a zone in which a non-zero gripping force (acting force) applied to a target from the acting part **51** does not vary even when the opening and closing members **26***b* and **26***c* are manipulated in the movable range of the opening and closing members **26***b* and **26***c*.

In this embodiment, a predetermined angle range (for example, 30 degrees) from the minimum value of the opening angle of the opening and closing members is set as the "gripping force increasing zone" in which the opening-closing member opening angle is proportional to the gripping force, and the other angle range, that is, the angle range from the present opening-closing member opening angle to the gripping force increasing zone, is set as the neutral zone.

When the opening-closing member opening angle is in the neutral zone, the opening angle (hereinafter, also referred to as an "end effector opening angle") of the pair of jaws **51**A and **51**B continues to be controlled and the manipulator controller **42** controls the motor controller **62** so that the opening angle does not vary and the gripping force does not vary. For example, a control signal is created to apply low current of an extent not to increase the gripping force to the motor **37**.

When an operator closes the opening and closing members **26***b* and **26***c* and the opening-closing member opening angle enters the gripping force increasing zone, the manipulator controller **42** creates a control signal so that the gripping force increases in proportion to the variation of the opening-closing member opening angle in the closing direction and the gripping force reaches a predetermined upper limit when the opening-closing member opening angle becomes the minimum value. In this embodiment, the control signal is created so that the current value increases as the opening and closing members **26***b* and **26***c* become closed based on the relational expression of a predetermined motor driving current value and the gripping force.

FIG. **7** is an example of a graph illustrating the relationship of the opening-closing member opening angle, the end effector opening angle, and the gripping force, where the opening-closing member opening angle θ_M is shown at the upper stage, the end effector opening angle θ_S is shown at the middle stage, and the gripping force F_S is shown at the lower stage. In a first zone R1 before a target is gripped by the acting part **51** (θ_M>opening angle θ_g at the gripping-start time) out of the movable range of the opening and closing members, the opening-closing member opening angle θ_M is proportional to the end effector opening angle θ_S. In the first zone R1, since a target is not gripped, the gripping force F_S is basically zero. A gripping force is slightly generated before and after the boundary between the first zone R1 in which a target is gripped and the neutral zone R2.

In the neutral zone R2 subsequent to the first zone R1, as the opening-closing member opening angle θ_M decreases, the end effector opening angle θ_S is constant and the gripping force FS does not increase but is kept constant.

In the gripping force increasing zone (acting force increasing zone) R3 subsequent to the neutral zone R2, as the opening-closing member opening angle θ_M decreases, the gripping force FS increases with a constant gradient and reaches the maximum gripping force F_{max} at the end of the gripping force increasing zone R3. The behavior of the end effector opening angle θ_S in the gripping force increasing zone R3 varies depending on the rigidity of the gripping target. For example, when the rigidity is high, the target is not deformed and thus the end effector opening angle θ_S has a tendency to hardly vary. However, when the rigidity of the target is low, the target is deformed with the increase in gripping force and thus the end effector opening angle θ_S decreases by a predetermined degree depending on the rigidity.

As described above, in the master-slave manipulator **1** according to this embodiment, it is determined that the gripping of a target by the acting part **51** is started based on the image from the camera **61**. Accordingly, the master controller **41** and the manipulator controller **42** of the control unit **4** controls the motor **37** to control the movement of the acting part **51** so that a predetermined angle range in the movable range of the end effector manipulating part **26** of the master arm **21** in the closing direction at that time is set to the gripping force increasing zone and the other range is set to the neutral zone. As a result, the gripping force applied to the acting part **51** when the end effector manipulating part **26** is manipulated in a predetermined angle range becomes the maximum gripping force F_{max} and the gradient indicating the relationship between the amount of manipulation of the end effector manipulating part **26** and the amount of increase of the gripping force in the gripping force increasing zone is constant, regardless of the size of the gripping target.

Therefore, it is possible to provide a surgical instrument which can be suitably controlled so that the gripping force applied to the acting part **51** is not excessive and in which the operational feeling of an operator does not vary even when the gripping target is changed.

In the surgical instrument according to the embodiment of the invention, it is necessary to set the movable ranges of the manipulation unit (the end effector manipulating part **26**) and the acting part **51** and the correspondence thereof so as to set the gripping force increasing zone of a predetermined angle range for the manipulation unit even when a possible smallest gripping target is gripped. For example, the movable angle range of the manipulation unit may be set to be greater than the movable range of the acting part **51**, or the ratio of the amount of manipulation of the manipulation unit and the amount of opening and closing of the acting part **51** may be adjusted to set the acting part to be opened and closed by a predetermined multiple of the amount of manipulation of the manipulation unit. The specific example thereof is not particularly limited.

A second embodiment of the invention will be described below with reference to FIGS. **8** and **9**. A master-slave manipulator **71** according to this embodiment is different from the master-slave manipulator **1**, in the configuration of the grip detecting unit and the positional relation between the gripping force increasing zone and the neutral zone in the movable range of the manipulation unit. In the following description, the same elements as described above are referenced by the same reference numerals and description thereof will not be repeated.

FIG. **8** is a block diagram illustrating the functional relation of the manipulator controller **42**, the distal end of the slave arm **31**, and the treatment tool **50** in the master-slave manipulator **71**. In FIG. **8**, similarly to FIG. **4**, connections to joints other than the manipulator controller **42** and the distal end of the slave arm are not shown.

In this embodiment, the slave manipulator **31** does not include a camera **61**. On the other hand, a force sensor **72** detecting a gripping force applied between a pair of jaws **51**A and **51**B is provided as the grip detecting unit to the acting part **51** of the treatment tool **50**. The value detected by the force sensor **72** is sequentially transmitted to the manipulator controller **42**.

The operation of the master-slave manipulator **71** according to this embodiment will be described below.

The manipulator controller **42** determines that a target is gripped between a pair of jaws **51**A and **51**B when the force sensor **72** starts detecting of the gripping force (when the gripping force becomes non-zero) with normal reference to the value detected by the force sensor **72**.

FIG. **9** is an example of a graph illustrating the relationship of the opening-closing member opening angle, the end effector opening angle, and the gripping force in the master-slave manipulator **71**, and the display pattern thereof is substantially the same as shown in FIG. **7**. In this embodiment, the manipulator controller **42** sequentially sets the gripping force increasing zone R3 and the neutral zone R4 in the closing direction of the opening and closing members **26***b* and **26***c* in the movable range (first movable range). Specifically, as shown in FIG. **9**, the gripping force increasing zone R3 of a predetermined angle range is set just after the first zone R1. Accordingly, the manipulator controller **42** creates a control signal and transmits the created control signal to the motor controller **62**, so that as the opening-closing member opening angle θ_M decreases after it is determined that a target is gripped between a pair of jaws **51**A and **51**B, the gripping force F_S increases with a constant gradient and reaches the maximum gripping force F_{max} at the end of the gripping force increasing zone R3. The gripping force applied to the acting part **51** is controlled based on the value detected by the force sensor **72**. A known feedback control may be applied to this control.

The movable range in the closing direction of the end effector manipulating part **26** after the value of the gripping force F_S reaches F_{max} is the neutral zone R4. In the neutral zone R4, the gripping force FS is kept F_{max} regardless of the decrease of the opening-closing member opening angle θ_M. Since the manipulator controller **42** controls only the value of the gripping force F_S based on the value detected by the force sensor **72**, the manipulator controller does not directly control the end effector opening angle θ_S, but the end effector opening angle θ_S is almost constant in the neutral zone R4.

In the master-slave manipulator **71** according to this embodiment, similarly to the master-slave manipulator **1** according to the first embodiment, it is possible to provide a surgical instrument which can be suitably controlled so that the gripping force applied to the acting part is not excessive and in which the operational feeling of an operator Op does not vary even when the gripping target is changed.

After it is determined that the gripping of a target is started, the gripping force increasing zone R3 is first set in the movable range in the closing direction of the end effector manipulating part **26**. Accordingly, when the operator Op closes the end effector manipulating part **26** after gripping the target, the gripping force applied to the acting part **51** increases at once. Therefore, the operator Op can perform the manipulation more intuitively.

Since the gripping force F_S in the gripping force increasing zone R**3** is controlled based on the value detected by the force sensor **72** disposed in the acting part **51**, it is possible to more accurately control the gripping force.

In this embodiment, the example in which the control of the gripping force is performed based on the value detected by the force sensor **72** is explained, but this configuration is not necessary. That is, although the accuracy is slightly low, it is also possible to control the gripping force by controlling a drive current value of the motor **37**, similarly to the first embodiment.

A third embodiment of the invention will be described below with reference to FIG. **10**. A master-slave manipulator according to this embodiment is different from the above-mentioned embodiments, in that a gripping force increasing zone and a neutral zone are set for the manipulation in addition to a control of the closing direction of the end effector manipulating part.

The mechanical structure of the master-slave manipulator according to this embodiment is the same as the master-slave manipulator **71** according to the second embodiment, and the control of the manipulation in the closing direction of the end effector manipulating part **26** is the same as in the second embodiment. In this embodiment, the manipulation in the opening direction (second direction) of the end effector manipulating part **26** is additionally subjected to a predetermined control.

FIG. **10** is an example of a graph illustrating the relationship of the opening-closing member opening angle, the end effector opening angle, and the gripping force in the master-slave manipulator according to this embodiment, and the display pattern thereof is substantially the same as shown in FIG. **9**. In FIG. **10**, the relationship of the opening-closing member opening angle θ_M, the end effector opening angle θ_S, and the gripping force F_S in the manipulation of the opening direction subsequently to the neutral zone R**4** in the manipulation of the closing direction is shown.

When the gripping force FS decreases based on the value detected by the force sensor **72**, the manipulator controller **42** determines that the manipulation of the end effector manipulating part **26** is performed in the opening direction and applies the control in the opening direction to creating a drive signal to the motor driver **62**. As shown in FIG. **10**, a gripping force decreasing zone (acting force decreasing zone) R**5** of a predetermined range is first set as the initial zone in the opening direction in the movable range (second movable range) in the opening direction. In the gripping force decreasing zone R**5**, as the opening-closing member opening angle θ_M increases, the gripping force F_S decreases with a constant gradient until the gripping force becomes zero.

Subsequently to the gripping force decreasing zone R**5**, a second zone R**6** in which the end effector opening angle θ_S increases with a constant gradient with the increase of the opening-closing member opening angle θ_M is set. In the second zone R**6**, the acting part **51** is separated from a gripping target and the grip is released. Similarly to the first embodiment, the end effector opening angle θ_S in the second zone R**6** is controlled by controlling the drive current of the motor **37**. After the acting part **51** is opened to the maximum, the other movable range in the opening direction of the opening and closing members **26***b* and **26***c* is set to a margin zone R**7** in which the acting part **51** does not move with the manipulation of the opening and closing members **26***b* and **26***c*.

The angle range of the gripping force decreasing zone R**5** varies depending on the state of the end effector manipulating part **26** just before performing the manipulation in the opening direction. In the example shown in FIG. **10**, since the end effector manipulating part **26** is manipulated in the closing direction up to the limit of the movable range including the neutral zone R**4** and is then manipulated in the opening direction, the angle range of the gripping force decreasing zone R**5** is matched with the gripping force increasing zone R**3**. For example, when the end effector manipulating part **26** is manipulated, for example, by 15 degrees in the closing direction up to the middle of the gripping force increasing zone R**3** and is then manipulated in the opening direction, the angle range of the gripping force decreasing zone R**5** is set to 15 degrees which is the same as the amount of manipulation in the closing direction in the gripping force increasing zone R**2**.

The gradient with which the gripping force decreases in the gripping force decreasing zone R**5** is set to a value obtained by multiplying the gradient, with which the gripping force increases in the gripping force increasing zone R**3**, by −1. By employing this configuration, the operational feeling given to the operator Op when increasing and decreasing the gripping force can be made to be constant in both the opening direction and the closing direction of the end effector manipulating part **26**.

In the master-slave manipulator according to this embodiment, similarly to the master-slave manipulators according to the above-mentioned embodiments, it is possible to provide a surgical instrument which can be suitably controlled so that the gripping force applied to the acting part is not excessive and in which the operational feeling of an operator Op does not vary even when the gripping target is changed.

The gripping force decreasing zone R**5** is set just after the manipulation in the opening direction of the end effector manipulating part **26** is started, and the manipulator controller **42** performs a control so that the variation gradient of the gripping force becomes the value obtained by multiplying the gradient in the gripping force increasing zone by −1. Accordingly, even in the operation of alternately repeating the manipulation in the closing direction and the manipulation in the opening direction to finely adjust the gripping force of the acting part, it is possible to suitably maintain the operator Op' operational feeling.

In this embodiment, the example in which the gripping force decreasing zone R**5** is set just after the manipulation in the opening direction of the end effector manipulating part **26** is started is explained, but the control in the opening direction is not limited to this configuration.

In a modified example shown in FIG. **11**, since a neutral zone R**8** is set just after the manipulation in the opening direction is started, the gripping force decreasing zone R**5** and the second zone R**6** are set subsequently thereto, the correspondence of the control details with the opening angle of the opening and closing members **26***b* and **26***c* is completely constant in both the closing direction and the opening direction. By employing this control, unlike FIG. **10**, even when the manipulation in the opening direction is performed after the end effector manipulating part **26** is closed to the limit, the opening-closing member opening angle at the time of releasing the grip and the opening-closing member opening angle at the time of starting the grip are matched with each other.

Accordingly, this modified example is suitable for the case where the operator Op prefers the correspondence between the opening-closing member opening angle and the end effector opening angle as the operational feeling.

The information of the detection device disposed in the grip section **21**A may be used instead of the value detected by the force sensor **72** to detect that the end effector manipulating part **26** is manipulated in the opening direction.

A fourth embodiment of the invention will be described below with reference to FIGS. **12** to **14**. A master-slave manipulator according to this embodiment is different from the master-slave manipulator according to the above-mentioned embodiments, in the use pattern of the attached treatment tool.

FIG. **12** is a diagram schematically illustrating a treatment tool **80** and an end effector manipulating part **90** in this embodiment. An acting part **81** includes a pair of jaws **81**A and **81**B similarly to the above-mentioned treatment tool **50**, but the pair of jaws **81**A and **81**B does not grip a target but is used to press and widen the target by opening. In correspondence therewith, a pair of opening and closing members **90***b* and **90***c* of the end effector manipulating part **90** is closed in the initial state and the operator Op opens the opening and closing members **90***b* and **90***c* to open the pair of jaws **81**A and **81**B. A hook may be appropriately provided to the pair of opening and closing members **90***b* and **90***c* so as to facilitate the opening manipulation.

In the master-slave manipulator according to this embodiment having the above-mentioned treatment tool **80** attached thereto, a pressing force acting on a target is controlled as an acting force by opening the pair of jaws **81**A and **81**B. Since the pressing force applied to the acting part **81** increases with the manipulation in the opening direction of the end effector manipulating part **90**, the opening direction is the first direction.

In the master-slave manipulator according to this embodiment, as shown in FIG. **13**, when a pressing target Sb**1** comes in contact with the outside surfaces in the opening and closing direction of the pair of jaws **81**A and **81**B, the manipulator controller **42** determines that the pressing on the pressing target Sb**1** is started. This determination may be performed using an image acquired with the camera or the like or may be performed based on the value detected by the force sensor or the like. However, since a widening treatment tool such as the treatment tool **80** often starts the pressing manipulation after the pair of jaws in a closed state is inserted into a gap between two tissues coming in contact therewith, it is not easy to determine the pressing start through the image process. Therefore, it is preferable that a reactive force acting on the pair of jaws from the pressing target be detected by the use of a force sensor or the like to determine that the start of the pressing.

FIG. **14** is an example of a graph illustrating the relationship of the opening-closing member opening angle, the end effector opening angle, and the gripping force in the master-slave manipulator according to this embodiment. The display pattern thereof is substantially the same as shown in FIG. **9** or the like, but the pressing force F_{S1} which is an acting force is a force acting in the opposite direction of the pressing force F_S and is thus expressed by a negative value.

As shown in FIG. **14**, the control in the opening direction of the pair of opening and closing members **90***b* and **90***c* is substantially the same as the control in the closing direction of the opening and closing members **90***b* and **90***c* in the second embodiment. That is, a first zone R**1***a* in which the opening-closing member opening angle θ_M is proportional to the end effector opening angle θ_S, a pressing force increasing zone R**9** in which the pressing force increases to the maximum pressing force F_{max} with a constant gradient, and a neutral zone R**10** in which the pressing force is maintained in F_{max} regardless of the value of the opening-closing member opening angle θ_M are sequentially set from the side on which the opening angle of the pair of opening and closing members **90***b* and **90***c* is the smallest.

Accordingly, when the pair of opening and closing members **90***b* and **90***c* is manipulated in the opening direction by a predetermined angle range from the time point at which the pressing is started, the correspondence between the amount of manipulation of the opening and closing members **90***b* and **90***c* and the pressing force is controlled so that the value of the pressing force becomes the maximum pressing force F_{max}. As a result, it is possible to maintain a predetermined operational feeling regardless of the type of the pressing target.

In this way, the surgical instrument and the control method thereof according to the above-mentioned embodiments of the invention can be applied to a surgical instrument having an end effector applying an acting force on a target by opening the end effector.

In this embodiment, the example in which the control is performed on only the manipulation in the opening direction in which the acting force increases is explained. In the same way of the third embodiment, in addition to the opening direction, the control may be performed in the closing direction of the pair of opening and closing members, which is the opposite direction. Similarly to the first embodiment, the order of the neutral zone and the pressing force increasing zone may be inverted.

While the embodiments of the invention have been described, the technical scope of the invention is not limited to the embodiments, but various modifications may be added to the elements or may be deleted, or the configurations of the embodiments may be combined without departing from the concept of the invention.

For example, as shown in a modified example shown in FIG. **15**, both the camera **61** and the force sensor **72** may be provided as the grip detecting unit. In this case, when determining whether the acting part comes in contact with a target, the manipulator controller appropriately selectively uses the image acquired by the camera **61** and the detection value of the force sensor **72** to be used or performs the determination based on both information pieces. Accordingly, it is possible to perform a more appropriate control.

Two neutral zones may be set with the acting force increasing zone interposed therebetween. Particularly, when a neutral zone of a small angle range (for example, of about several degrees) is disposed between a zone such as the first zone in which the acting part comes in contact with a target and the acting force increasing zone, the neutral zone serves as a "margin" and a non-gripped state can be smoothly transferred to a gripped state, thereby improving the operational feeling.

When the neutral zone precedes the acting force increasing zone after the acting part comes in contact with a target, it may be difficult to see the boundary between the neutral zone and the acting force increasing zone. Accordingly, when the amount of manipulation of the manipulation unit reaches the boundary, a signal which can be recognized by the operator may be sent. The type of the signal is not particularly limited, but all the types of signals such as a visual signal of light or the like, an auditory signal of sound or the like, and a signal for causing the movement of the opening and closing members to be heavier for a quick moment can be used.

Similarly, when the neutral zone is set subsequent to the acting force increasing zone and a signal which can be recognized by an operator is sent at the boundary between the acting force increasing zone and the neutral zone, the operator does not manipulate the manipulation unit to the limit to further increase the acting force even in the neutral zone. As a result, it is possible to suppress an unnecessary manipulation.

The surgical instrument according to the embodiments of the invention is not limited to the master-slave manipulators described in the above-mentioned embodiments. The surgical instrument according to the invention may be applied to, for example, a surgical instrument in which the manipulation part and the end effector are disposed in the same body and a remote manipulation is not performed.

The manipulation unit is not limited to the configuration having a pair of opening and closing members. For example, a configuration including a manipulation member which can get closer to and be separated from a base and opening and closing the acting part by bringing the manipulation member closer to and separated from the base may be used. Various manipulations such as a sliding manipulation, a twisting manipulation, and a pushing manipulation in the first direction and the second direction may be employed instead of the closing manipulation and the opening manipulation.

The maximum value of the acting force may be set to a desired value through the use of various input mechanisms such as a switch or a dial or a user interface displayed on the display unit.

While preferred embodiments of the present invention have been described, the present invention is not limited to the embodiments.

Additions, omissions, substitutions, and other variations may be made to the present invention without departing from the spirit and scope of the present invention. The present invention is not limited by the above description, but by the appended claims.

The invention claimed is:

1. A surgical instrument comprising:

an end effector that is opened and closed;

a manipulation unit which has an opening and closing member that is capable of opening and closing and which is configured to open and close the end effector by manipulating the opening and closing member in a first direction by a user so that the end effector applies an acting force to a target;

a grip detecting unit configured to acquire an information to determine whether the end effector applies the acting force to the target;

a driving unit configured to drive the end effector to be opened and closed; and

a control unit configured to control the driving unit based on the information input to the manipulation unit,

wherein when the control unit determines that the end effector applies the acting force to the target based on the information acquired by the grip detecting unit, the control unit:

sets an acting force increasing zone of a predetermined range in a first movable range in the first direction of the opening and closing member,

sets a neutral zone in a remaining area of the first movable range,

controls the driving unit so that the acting force increases with a constant gradient with respect to an amount of manipulation of the manipulation unit in the acting force increasing zone, and

controls the driving unit so that the acting force is kept constant and non-zero regardless of the amount of manipulation of the manipulation unit in the neutral zone.

2. The surgical instrument according to claim **1**, wherein the acting force increasing zone is set in an initial area toward the first direction in the first movable range.

3. The surgical instrument according to claim **1**, wherein the grip detecting unit includes a camera imaging the end effector.

4. The surgical instrument according to claim **1**, wherein the grip detecting unit includes a force sensor detecting the acting force.

5. The surgical instrument according to claim **1**, wherein the first movable range of the manipulation unit is set to be greater than a movable range of the end effector.

6. The surgical instrument according to claim **2**, wherein the acting force decreases when the opening and closing member is manipulated in a second direction, and

wherein when the opening and closing member is manipulated in the second direction, the control unit

sets an acting force decreasing zone of a predetermined range to an initial area toward the second direction in a second movable range of the second direction of the manipulation unit, and

controls the driving unit so that the acting force decreases with a constant gradient with respect to the amount of manipulation of the manipulation unit in the acting force decreasing zone.

7. A control method of a surgical instrument having an end effector that is opened and closed and a manipulation unit which has an opening and closing member that is capable of opening and closing and which is configured to open and close the end effector by manipulating the opening and closing member in a first direction by a user so that the end effector applies an acting force to a target, the control method comprising:

repeatedly determining whether the end effector applies the acting force to the target;

when determining that the end effector applies the acting force to the target,

setting an acting force increasing zone of a predetermined range in a first movable range in the first direction of the opening and closing member,

setting a neutral zone in a remaining area of the first movable range;

causing the acting force to increase with a constant gradient with respect to an amount of manipulation of the manipulation unit in the acting force increasing zone; and

causing the acting force to be kept constant and non-zero regardless of the amount of manipulation of the manipulation unit in the neutral zone.

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